

Scientific Objectives of Solar Gamma-Ray Observations

R. E. Lingenfelter

University of California, San Diego

Solar flare neutrons and gamma rays are produced by nuclear interactions of flare accelerated ions in the solar atmosphere. A rich variety of such gamma ray and neutron observations have been made by the SMM, other satellite, balloon and ground based detectors, and they have provided a wealth of unique information on the nature of particle acceleration in flares and on flare process itself. What we have learned from these observations was briefly reviewed, and what we can hope to learn from more sensitive new observations to be made with the Gamma Ray Observatory (GRO), the MAX 91 balloon program, and the Nuclear Astrophysics Explorer was outlined.

The observations have shown that the observed gamma rays and neutrons were produced mainly in thick target interactions of accelerated ions trapped on magnetic loops and running their range in solar atmosphere; they could not have been produced in thin target interactions of ions which escaped into the interplanetary medium because the abundances of spallation products, such as Li, B, T and D, would exceed those observed. Comparisons of the number of accelerated protons required to produce the observed gamma rays and neutrons with the number observed in the interplanetary medium show that the fraction of accelerated protons that escape into the interplanetary medium from impulsive flares varies greatly from 0.002 to 0.98 with the largest escape fractions occurring in the largest flares, where the accelerated ion energy density can exceed that of the confining magnetic field.

The neutron and gamma ray observations also show that the energy spectra of the accelerated protons trapped at sun have a form consistent with an exponential or a Bessel function in momentum, as would be expected from stochastic acceleration, rather than a power law as would be expected from shock acceleration. The energy spectra of the accelerated protons in the interplanetary medium also generally seem to be roughly the same as that of those trapped at the Sun suggesting that the process of proton escape from most impulsive flares is energy independent. In the longer duration flares, however, the protons observed in the interplanetary medium may have power law spectra suggesting subsequent shock acceleration of the escaping ions. The observed time dependence of the prompt gamma ray line emission also requires that the ions trapped on converging magnetic loops be precipitated rapidly by MHD turbulent pitch angle scattering, which may also be responsible for their acceleration.

The forthcoming solar flare gamma-ray and neutron observations with the more sensitive detectors of BATSE, OSSE, COMPTEL and EGRET on the GRO should give a wealth of important new information. In particular:

New constraints on ion acceleration, pitchangle scattering, magnetic mirroring, energy spectra and angular distributions should be obtained from measurements of the time-dependence of the nuclear lines versus that of the π^0 decay and π^\pm bremsstrahlung gamma rays, as well as from direct measurements of the neutron spectra versus time and solar longitude.

Direct determinations of the accelerated alpha particle to proton ratio can be obtained from measurements of the alpha-particle produced Be and Li deexcitation gamma rays versus those of the predominantly proton-excited C and O.

A unique determination of the photospheric density scale heights in flare regions can be obtained from measurements of the Compton scattered continuum just below the 2.223 MeV line from deep neutron capture on hydrogen.

More extensive and more precise chromospheric/photospheric abundances can be determined from more sensitive measurements of nuclear deexcitation lines from a wider range of elements, and better determination of the photospheric $^3\text{He}/\text{H}$ ratio can be made from more sensitive measurements of the time dependence of the 2.223 MeV line.

In addition, high resolution gamma-ray spectroscopy of solar flares from Ge spectrometers flown in the MAX-91 balloon program and on the Nuclear Astrophysics Explorer will give much more sensitive measurements of all of the properties discussed above and provide much unique new information, such as:

Independent determinations of the angular distributions and energy spectra of interacting accelerated ions from high resolution measurements of the nuclear deexcitation line profiles and asymmetries.

Direct determinations of the temperature, density and ionization fraction in the flare interaction regions from high resolution measurements of the shape and temporal evolution of the 511 keV line and 3-photon positronium continuum.

Time-dependent determinations of the properties of both the thermal and nonthermal plasmas in flares from high resolution measurements of the hard X-ray continuum spectrum versus time.